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Survival Analysis of Cereal Crop Variety Innovations in the UK

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Abstract

This paper explores the changing survival patterns of cereal crop variety innovations in the UK since the introduction of plant breeders' rights in the mid-1960s. Using non-parametric, semi-parametric and parametric approaches, we examine the determinants of the survival of wheat variety innovations, focusing on the impacts of changes to Plant Variety Protection (PVP) regime over the last four decades. We find that the period since the introduction of the PVP regime has been characterised by the accelerated development of new varieties and increased private sector participation in the breeding of cereal crop varieties. However, the increased flow of varieties has been accompanied by a sharp decline in the longevity of innovations. These trends may have contributed to a reduction in the returns appropriated by plant breeders from protected variety innovations and may explain the decline of conventional plant breeding in the UK. It may also explain the persistent demand from the seed industry for stronger protection. The strengthening of the PVP regime in conformity with the UPOV Convention of 1991, the introduction of EU-wide protection through the Community Plant Variety Office and the introduction of royalties on farm-saved seed have had a positive effect on the longevity of protected variety innovations, but have not been adequate to offset the long term decline in survival durations.

Keywords: Survival Analysis, Plant Variety Protection, Intellectual Property Rights

JEL classification: Q12, Q16

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Introduction

The post-1985 period in the UK has been a period of significant changes in the organisation of agricultural research. The key changes included reduced funding for public sector research, greater reliance on the private sector for "near-market" research and privatisation of some important agricultural research institutions like the Plant Breeding Institute (Thirtle, Palladino and Piesse: 1997). Greater reliance on the private sector for commercial plant breeding was supported by an intellectual property rights (IPR) regime for plant variety innovations (Plant Variety Protection) introduced in the UK the late 1960s. The expectation was that the IPR regime would facilitate the private appropriation of economic returns from innovations, thus encouraging private sector investment in plant breeding research. The post-1985 period has clearly witnessed a significantly enhanced role for the private sector in the commercial plant breeding of several agricultural crops and an increased flow of varieties protected through Plant Variety Protection (PVP). However, there appears to be considerable evidence that conventional plant breeding in the UK has been declining over the last two decades (Murphy: 2007). This has been attributed by the seed industry to the declining economic returns from plant breeding and has led to calls for a much stronger regime of protection. There are two principal determinants of the of the economic returns that can be appropriated from plant variety innovations – the first is the duration for which innovations survive under protection and the second is the returns (royalties) from product sales that can be appropriated during the period of protection. This paper examines the trends in the longevity of protected wheat variety innovations in the UK and the determinants of survival durations focusing on the IPR regime and the changes made to it over the last four decades. We examine how changes to the IPR regime and other institutional changes have influenced survival durations of new wheat varieties in the UK. The analysis provides insights into the incentive effects of the IPR regime and how they may have changed over time.

Plant Variety Protection in the UK

Plant Variety Protection (PVP) is a form of intellectual property protection for new varieties of plants that is akin to patents but with some important differences. The criteria for protection under PVP are the "Distinctness, Uniformity and Stability" of a new variety (which is different from the criteria of novelty, inventiveness and utility or industrial application used in the case of patents). Two important differences between PVP and patents are that PVP generally allows for farmers' privilege and breeders' exemption, which are not allowed under patents. The former allows farmers to use seeds of a protected variety saved from the harvest for replanting their land in subsequent seasons without payment of royalty to the breeder and the latter allows researchers to use a protected variety as an "initial source of variation" in the development of other new varieties. Farmers' privilege and breeders' exemption in PVP system recognise the special characteristics of plant variety innovations- the self-reproducing nature of these innovations which has supported the farm seed-saving tradition for centuries and the sequential nature of innovations where new variety innovations are derived from the development of existing varieties. However, farmers' privilege and breeders' exemptions tend to make PVP a somewhat weaker form of IPR protection as they limit the private appropriation of returns from innovations compared to patents. As the role of the private sector in commercial plant breeding has increased there has been a persistent demand from the seed industry to strengthen the IPR regime to provide improved incentives for innovation.

PVP legislation in the UK was introduced in 1964 and the first PVP certificates were issued in 1967. UK's legislation conformed to the UPOV Convention – the International Convention for the Protection of New Varieties of Plants that seeks to harmonise standards of protection across member-countries and includes provisions for "national treatment" and "right of priority"[1]. The duration of protection for different species ranged from 15 to 20 years. For nearly two decades after inception, the only change in the PVP legislation was the extension of coverage to a larger number of genera and species. Major changes to the legislation were introduced in 1994, when the UK legislation was amended to bring it in conformity with the revised UPOV Convention of 1991. The revision of the UPOV Convention in 1991 was intended to significantly strengthen the protection afforded to breeders by PVP systems. The revision restricted the scope of farmers' privilege, which could be provided only as an exception to the breeders' rights. This paved the way for the introduction of royalties on the use of farm-saved seed of protected varieties providing additional revenue streams for certificate holders. Royalties on the use of farm-saved seeds for major agricultural crop species were introduced in the UK in 1998 under an arrangement whereby the collection of farm-saved seed royalties was entrusted to the British Society of Plant Breeders, an industry body. The revision introduced the concept of "Essentially Derived Varieties" and extended the rights of breeders over such varieties which were close derivatives of protected varieties. The rights of breeders were extended to harvested material of the crop in cases where the breeders had not had an opportunity to exercise the rights in respect of the propagating material or seeds. The introduction of an EU-wide system of PVP through the Community Plant Variety Office (CPVO) was a major landmark in the development of PVP systems. It allowed breeders to obtain protection for a breeder to obtain protection in all EU countries through a single application made to the CPVO, significantly reducing transaction costs for breeders in obtaining protection in multiple countries. The EU legislation also allowed varieties protected under national PVP systems to switch to EU-wide protection through the CPVO.

In most national PVP systems and in the CPVO, breeders are required to pay an annual renewal fee to keep the protection in force. Renewal fees are set and periodically revised by the PVP authorities. The survival duration of a new variety under protection, therefore, depends on the breeders' decision whether or not to renew a PVP certificate at the end of each year of protection. PVP certificates are not traded in the market and, therefore, their market values are not directly observable. However, the survival patterns of PVP certificates can be observed.

Theoretical Model Explaining Survival of Protected Varieties

Upon acquiring a Plant Variety Protection (PVP) certificate, the holder has to decide in each of the subsequent years over the lifespan of the certificate whether to renew it or not. Renewal is associated with a fee and in some cases may incur variety "maintenance" costs. Failure to renew the certificate leads to termination of plant breeders' rights-this may happen voluntarily or involuntarily. The duration for which protection is maintained can be modelled as the outcome of utility maximization by the certificate holder (Chambers and Foster; 1983). Let U_{ij} be the utility the holder obtains from holding the PVP certificate with $j=\{1,0\}$ indicating whether the certificate is surrendered or not and $i=\{1,2,....n\}$ indexing the holders as well as the characteristics of the variety. Assuming a well-behaved function of utility of the form,

$$U_{ij} = X_i \beta_i + \varepsilon_j \quad j = 0,1 \text{ and } i = \{1,2,...,n\}$$

[1] Note that PVP legislation is national in scope – if a variety is to be protected in several countries then the innovator has to apply for and obtain protection in each country separately under the respective national legislation. "National treatment" requires that PVP legislation in a country should provide the same treatment to foreign applicants as is provided to nationals. "Right of priority" gives an applicant for protection in one UPOV member-country the priority for filing an application for protection in other UPOV member-countries for a certain period. The UPOV Convention of 1961 was revised in 1978 and again in 1991.

The certificate has to choose between two mutually exclusive alternatives. The breeder either renews the PVP certificate, $j=1$, or does not, $j=0$. It is assumed that the PVP certificate holder (innovator) chooses the alternative which yields the highest level of utility. The ith innovator will choose to renew the certificate if $U_{i1} > U_{i0}$. If the qualitative variable K_i indexes the renewal decision, while π is the probability of the ith innovator renewing the certificate, it implies that

$$K_i = 0 \Rightarrow U_{i0} \geq U_{i1} \text{ and } K_i = 1 \Rightarrow U_{i1} > U_{i0}$$

So that,

$$\begin{aligned}\pi &= \pi(K_i = 1) = \pi(U_{i1} > U_{i0}) = \pi(X_i\beta_1 + \varepsilon_{i1} > X_i\beta_0 + \varepsilon_{i0}) \\ &= \pi(\varepsilon_{i1} - \varepsilon_{i0} > X_i\beta_0 - X_i\beta_1) = \pi(\varepsilon_{i1} - \varepsilon_{i0} > X_i(\beta_0 - \beta_1)) \\ &= \pi(\mu_i > X_i\beta) = \Phi(X_i\beta)\end{aligned}$$

where $\mu_i = \varepsilon_{i1} - \varepsilon_{i0}$ and $\Phi(X_i\beta)$ is the cumulative density function for μ_i. This implies that the probability of the ith innovator renewing the PVP certificate is the probability that the utility of renewing the certificate is higher than that of surrendering it.

In the above formulation, the renewal decisions of breeders are likely to be bases on an assessment of the potential benefits and costs associated with renewal. Returns or benefits accrue by way of PVP royalties on the volume of seed sold. The PVP royalties that can be demanded by a certificate holder and the market share that can be garnered by a protected variety will depend on a number of factors including the characteristics of the variety (i.e., the yield and/or other agronomic advantages that it offers), the strength and effectiveness of the IPR regime, the market structure and the degree of competition from existing and new varieties in the market.

Empirical Modelling of Survival Durations

Survival Models

The basic survival function models the probability distribution of duration and can be presented as follows (Kiefer: 1988, Lawless: 2003).

Let T be a non-negative variable representing the lifetime of a process, or time to an event, having the probability density function *f(t)* and cumulative distribution function F(t), where

$$F(t) = \Pr(T \leq t) = \int_0^t f(x)dx$$

This model specifies the probability that the random variable *T* may be less than some value *t* .Then, the probability of some process surviving at least to time *t* is given by

$$S(t) = \Pr(T \geq t) = \int_t^\infty f(x)dx = 1 - F(t)$$

S(t) is the survival function. A survival density function can be defined as:

$$s(t) = S'(t) = \frac{dS(t)}{dt} = \frac{d}{dt}[1 - F(t)] = -f(t)$$

An interesting parameter that can be computed from survival models is the hazard rate which measures how the risk of an outcome, changes over time. In other words it measures the probability of failure in the next small interval (between *t* and *t + Δt*) having already survived till the beginning of the interval. The survivor function and the density function are the two important components of the hazard function. A hazard function *h(t)* in other words indicates the instantaneous rate of death or failure at time *t*, that is, the probability of the event in the next infinitesimal unit of time, given that the individual has survived up to time *t*. It is expressed as follows:

$$h(t) = \underset{\Delta t \to 0}{Lim} \frac{\Pr(t \le T < t + \Delta t \mid T \ge t)}{\Delta t} = \frac{f(t)}{S(t)}$$

The hazard function shows how the risk of failure varies with age or time. It must be non-negative and its integral over [0, ∞) must be infinite (Lawless 2003; Nikzad 2011). It may be increasing or decreasing, non-monotonic or discontinuous. In the context of plant variety protection, the hazard function can be interpreted as the probability of surrender of a PVP certificate given that the plant variety right has already survived *t* years. A cumulative hazard function is related to all the previous three functions and defined from the hazard function as follows:

$$H(t) = \int_0^t h(x)dx = -\log S(t)$$

Non-Parametric Models

We first examine the survival patterns of PVP certificates using the non-parametric Kaplan-Meier (Kaplan and Meier: 1958) survival curves. The Kaplan-Meier (KM) estimator is the product of survival probabilities modelled as follows:

$$\hat{S}_{KM}(t) = \prod_{t_i < t} \frac{n(t_i) - d(t_i)}{n(t_i)}$$

Where *t* indexes time, n is the number of PVP certificates at risk and *d* is the number of failures (surrenders of PVP certificates). The KM curve appears as a step function which equals the empirical survival distribution in the absence of censoring (Nikzad 2011). We compare the patterns of survival across decades, before and after introduction of changes to the PVP regime and across different categories of PVP certificates (e.g., owned by private sector versus owned by public sector, owned by foreign entities versus owned by UK entities etc).

Semi-Parametric and Parametric Models

For the empirical modelling of survival durations, we use semi-parametric and parametric models. The semi-parametric model that we use is the extended Cox model (Cox: 1972, Hougaard: 2000) which is an extension of the Cox Proportional Hazard (PH) model. In the Cox-PH model the hazard of failure (i.e., the probability of surrender of a PVP certificate) is:

$$h(t \mid X) = h_0(t)\exp(\sum_{i=1}^{p}\beta' x_i)$$

where h denotes the hazard rate and
t= time
X= vector of covariates influencing survival
p= number of explanatory variables
β= vector of regression coefficients.
The model gives the expression for the hazard at time *t* for an individual with a given set of explanatory variables (X_i). Hazard at time *t* is the product of two quantities. The first $h_0\ (t)$ is the baseline hazard function. The second quantity is the exponential expression e to the linear sum of $\beta_i x_i$ over *p* explanatory variables. An important feature of the Cox-PH model that concerns the PH assumption is that the baseline hazard function is a function of *t* but does not involve the *X'*s. By contrast the exponential expression involves the *X'*s but does not involve *t*. The PH assumption requires that the "hazard ratio" is constant over time, that is, the hazard for one individual is proportional to the hazard for any other individual, where the proportionality constant is independent of time. The model can be estimated without knowledge of the underlying baseline hazard function $h_0\ (t)$. The coefficients model the changes in the hazard of failure as a result of changes in x_i's, so that a positive co-efficient means that an increase in the value of the explanatory variable leads to an increase in the risk of failure and vice-versa (Cox: 1972). If the proportional hazard assumption is correct, then it follows that the increase in the hazard ratio due a unit increase in x_k will be $e^{\beta k}$ and the percentage change in the hazard rate due to a unit increase in x_k will be $e^{\beta k}-1$. The main advantage of the Cox-PH model is that the effect of the covariates on the hazard can be estimated without knowing the baseline hazard function. It is also a "robust" model in that the results from using the Cox model will closely approximate the results from the correct parametric model. It should be noted, however, that it is often difficult to find an economic rationale for the PH assumption. The Cox-PH model can be extended to accommodate time-varying covariates[2] as well as stratification and frailty. We use an extended Cox model as some of our explanatory variables (e.g., the quantity of seed sold each year) are time-varying covariates. Parametric models require an assumption regarding the underlying distribution of the hazard function and can be used if the correct form of the hazard function is known. In practice it is difficult to be certain where a given parametric model is appropriate. The most commonly used distributions are the Exponential, Weibull, Lognormal and Log-Logistic distributions. (Woolridge: 2002)Their density, survival and hazard functions are summarized in Table-1.

Table 1: Density, survival and hazard functions for selected parametric models

Distribution	**Density Function f(t)**	**Survival Function S(t)**	**Hazard Function λ(t)**
Exponential	$\lambda\, exp(-\lambda\ t)$	Exp(-λ t)	λ
Weibull	$\lambda\, p(\lambda\ t)^{p-1}\, exp(-(\lambda\ t)^{p})$	Exp[- (λ t)^{p}]	$\lambda\ p\ (\lambda\ t)^{p-1}$
Lognormal	[p/ (λ t)]φ (-plog(λ t))	Φ(-plog(λ t))	[p/(λ t)]φ (-plog(λ t))/ Φ(-plog(λ t))
Log-Logistic	$\lambda\, p(\lambda\, t)^{p-1}/(1+ (\lambda\ t)^{p})^{2}$	1 / (1+(λ t)^{p})	$\lambda\ p(\lambda\ t)^{p-1}/(1+(\lambda\ t)^{p})$

2 In the extended Cox model incorporating time-varying covariates the PH assumption is not satisfied. Incorporating time-varying covariates in the extended Cox model is much easier than in parametric models.

The non-parametric (Kaplan-Meier) analysis of survival functions suggested that the hazard function may be non-monotonic. We, therefore, considered the lognormal and log-logistic functions as they can accommodate non-monotonic hazard functions. We selected the lognormal function for our empirical estimation based on the Akaike Information Criterion (AIC) and the Schwarz Bayesian Criterion (SBC). In our empirical analysis, we present the results of the extended Cox model and the parametric lognormal model, both incorporating time varying covariates, for comparison.

A brief description of the variables used in the empirical survival models and their expected impacts is given below:

Quantity of seed certified: This is used as a proxy for the quantity of seed of a variety sold in the UK. Prior to the introduction of PVP royalties on farm-saved seed in the UK in 1998, breeders of protected varieties were able to seek royalties only on the certified seed sales of a variety. As PVP royalties are related to the volume of seed sold, it follows that a larger volume of seed sales would increase returns accruing to breeders (PVP holders) and increase the probability of renewal of a variety.

Protected after 1994 (dummy): In the early 1990s, there was a persistent demand from the seed industry for stronger protection for new varieties and for royalties on the use of farm-saved seed of protected varieties to offset declining returns realised by breeders from new varieties. UK PVP legislation was amended in 1994 to bring it into conformity with the UPOV Convention of 1991. This dummy is used to assess whether changes in the UK PVP legislation to strengthen protection offered to breeders had the effect of increasing survival durations – thereby increasing returns that could be appropriated by breeders from protected new varieties.

Protected under CPVO (dummy): After the introduction of EU-wide protection through the CPVO in 1995, breeders have the option of protecting a new variety either under the UK PVP legislation or through the CPVO. Varieties protected EU-wide through the CPVO are likely to be those that have market potential in a number of EU countries. A variety that is protected in other EU countries in addition to the UK is likely to have seed sales in those countries that will generate royalties for the breeder and, hence, will have a higher probability of renewal of protection. We would expect CPVO-protected varieties to have longer survival durations than UK-protected varieties.

Switch to CPVO protection (dummy): Varieties protected under UK PVP legislation could be switched to EU-wide protection (with protection under UK PVP legislation remaining suspended) after the introduction of the CPVO. Breeders would be likely to switch to CPVO protection in respect of varieties which had market potential in EU countries other than the UK. The larger market potential of these varieties would be expected to lead to longer survival durations.

Grant year 1998 or later (dummy): 1998 was the year when plant breeders were allowed to collect royalties on farm-saved seed (on varieties granted protection after a cut-off date) following EU-legislation and amendments to the UK PVP legislation. It is to be expected that varieties on which collection of royalties on farm-saved seed was allowed (albeit at a lower rate than on certified seed) would have a higher probability of survival in any given time period than varieties on which royalties could be collected only on certified seed sales.

Variety produced by public sector or private sector (dummy): Prior to the mid-1980s, the public sector was dominant in the development of new wheat varieties in the UK. The mandate of the public sector was to achieve widespread dissemination of improved varieties and successful varieties survived for long durations (10-20 years or more). Varieties developed by the private sector may have shorter survival duration if the private sector seeks a quicker turnover of varieties in the pursuit of marketing advantage (e.g., “planned obsolescence”) or if the introduction of new varieties is used a strategy for increasing market share.

Variety produced in the UK or outside (dummy): Varieties produced by UK companies may be specifically adapted to local agro-climatic conditions and have a market only in the UK. Varieties produced by foreign companies or breeders may be more widely adapted for being grown in several countries. This may imply that varieties produced by foreign entities may have longer survival duration

Variety owned by one of the top five PVP holders for wheat: The concentration of ownership of PVP certificates for wheat varieties may affect the survival duration of individual varieties. Varieties owned by the top firms (in terms of PVP holdings) may exhibit a different survival pattern than varieties owned by smaller firms. However, the effect of ownership by one of the top companies on survival duration is uncertain. It is not clear whether the varieties owned by top firms would remain in the market longer or would be replaced faster by newer varieties.

Degree of competition: The survival duration of protected varieties may be influenced by the degree of competition in the market, especially from new varieties introduced by competing firms. We use the number of protected varieties in the market with a positive market share in each year as an index of the competition faced by new varieties. A higher degree of competition is likely to lead to lower survival durations.

Decadal dummies: In this model we are focusing mainly on IPR related variables as determinants of survival durations of protected varieties. The decadal dummies are used to capture the effects of other institutional changes (e.g., agricultural research policies and changing market structure in the seed industry) on survival durations.

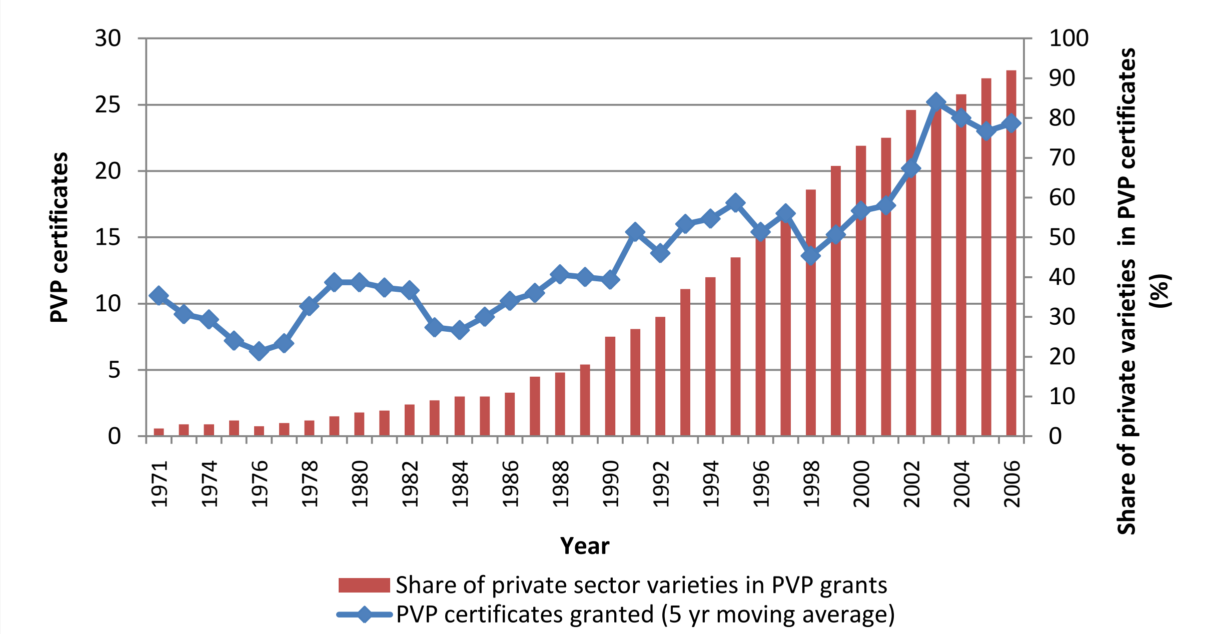
Data

Data on PVP certificates, their grant dates and expiry dates and their ownership were taken from the monthly *Plant Varieties and Seeds* Gazettes (1964-2006) brought by DEFRA and from UPOV’s PLUTO database of PVP certificates issued in all member-countries of UPOV. Data on seed certification were obtained from the National Institute of Agricultural Botany’s periodicals on seed certification statistics. The status of owners (e.g., whether they are private companies, or foreign entities etc) were ascertained using business databases accessed through the British Library. This study is based on a dataset of 628 wheat varieties produced between 1964 and 2006. As seed certification data was available on a consistent basis only from 1983, the estimation of the extended Cox model and the lognormal parametric models were based on 380 varieties that were protected between 1983 and 2006 or had been protected earlier but had positive seed weights certified after 1983.

Results

Figure-1 shows the trends in the grants of PVP certificates for new varieties for wheat in the UK from the inception of the PVP legislation in 1964 to 2006 and the share of private sector varieties in PVP grants. As the number of grants can vary from year to year on account of administrative reasons (e.g., lags in getting test reports) we use a five year moving average of grants to illustrate the trends. There has been a steady upward trend in the flow of protected new varieties of wheat over the last four decades. The share of the private sector in PVP grants has seen a dramatic increase since the mid-1980s and new variety development is now almost completely dominated by the private sector. This shift towards the private sector appears to have followed major agricultural policy changes in the UK placing greater reliance on the private sector for "near-market" research, reduced funding for public sector research and the privatisation of the Plant Breeding Institute in Cambridge which was the leading public sector breeder of wheat varieties in the UK.

Figure-1: Trends in Grants of PVP Certificates and Share of Private Sector Varieties



Kaplan-Meier Survival Curves

Figure-3 shows the distribution of survival times for all PVP grants from 1964 to 2006 based on the Kaplan-Meier estimator. The average survival duration is 5.94 years and less than 3% of the varieties survive for more than 15 years although the maximum allowable duration of protection is 20 years.[3] The smoothed hazard curve shown in Figure-4 suggests that the hazard of failure (i.e., the surrender of a PVP certificate) is non-monotone function and varies with the survival duration. There is a sharp jump in the hazard rate as the survival duration approaches the maximum duration of protection. We are mainly interested in the differences in the survival patterns of PVP certificates across different strata defined by the covariates discussed above. The differences in the Kaplan-Meier survival curves of PVP certificates stratified by grant decades, PVP regime changes and ownership characteristics of protected varieties are summarised in Table-2. Survival curves for selected strata are shown in Figures-4-7. The significance of the differences between survival curves in different strata were assessed using the Log Rank test.

[3] Increased to 25 years after the UK PVP legislation was amended in 1994 to bring it conformity with the UPOV 1991 Convention.

Table-2: Comparison of Kaplan Meier Survival Curves of PVP Certificates by Strata

Category		Survival Duration (years)		
	Count of certificates (N=628)	**25th percentile**	**50th percentile**	**75th Percentile**
By decades				
1960s cohort	36	3	6	9.92
1970s cohort	87	2	5	8.83
1980 cohort	124	1.89	4.01	9.09
1990s cohort	212	1.98	3.41	8.21
2000s cohort	169	1.22	4.14	6.15
EU legislation/UPOV 1991				
Pre-1995 cohorts	342	2	4.12	8.83
Post 1995 cohorts	286	1.96	4	9.2
Royalties on farm-saved seed				
Pre-1998	393	2	4	8.14
Post-1998	235	1.92	4.37	9.1
Public versus private ownership				
Public	148	2	4.94	9
Private	480	1.99	4	8.21
EU-wide protection through CPVO				
UK protection only	542	1.8	3.46	8
EU-wide protection through CPVO	86	4.91	9	20
Developed by foreign or domestic firm				
Non-UK firm	198	2.13	6	10
UK firm	430	1.89	3.78	8
Whether switched to CPVO protection				
UK PVP protection only	609	1.93	4	8.64
Switched to CPVO protection	19	6.75	14.03	14.7
Produced by top-5 company				
Top-5 company	399	1.92	4.14	9
Non-Top-5 company	299	2	4	9

Figure-2: Distribution of survival durations of PVP Certificates (1964-2006)

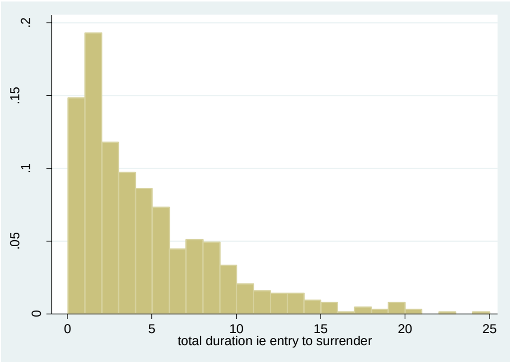


Figure-3 : Smoothed hazard estimate for surrender of PVP certificates

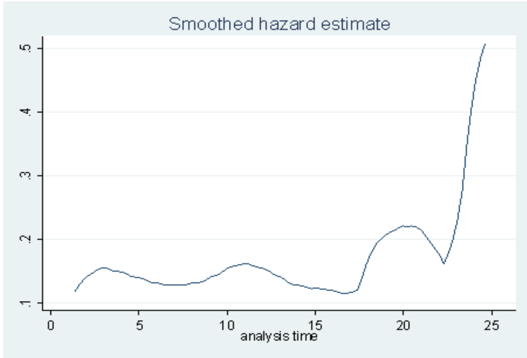


Figure-4: Survival curves by decade of grant of PVP certificates

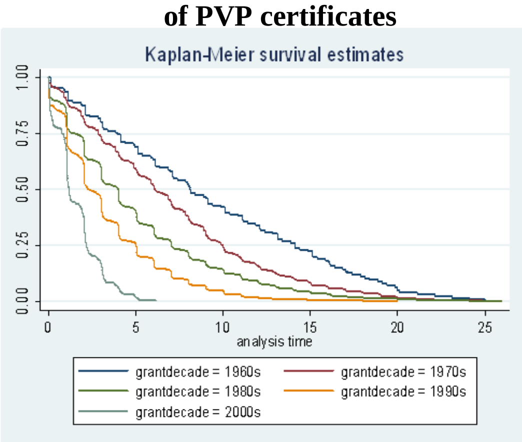


Figure –5: Survival curves before and after introduction of EU-wide protection

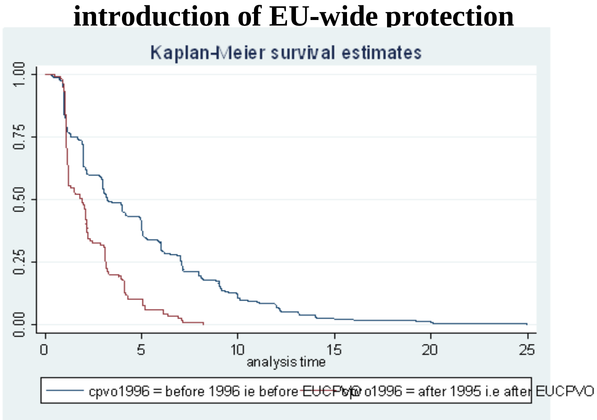


Figure-6: Survival curves of varieties produced within and outside the UK

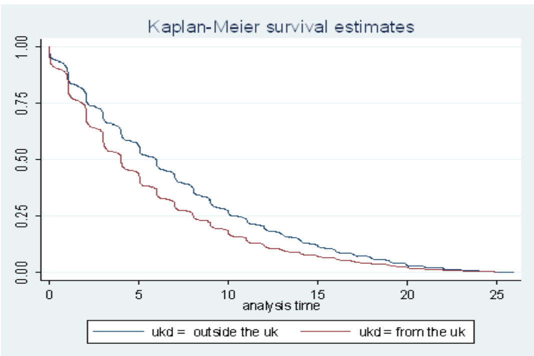


Figure-7: Survival curves before and after introduction of royalties on farm-saved seed of protected varieties

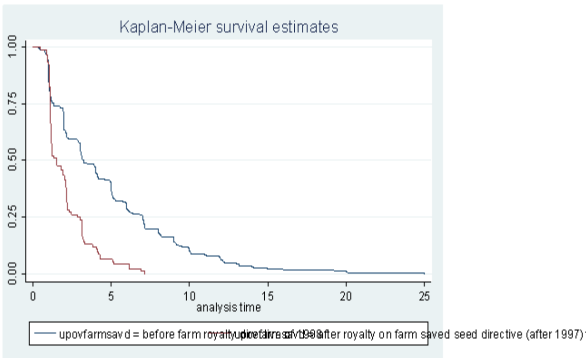


Table-2 shows that the median survival durations declined from 6 years in the 1960s to 3.41 years in the 1990s before increasing marginally in the 2000s. The introduction of royalties on farm-saved seed appears to have increased survival durations. Varieties which are protected EU-wide through the CPVO and sold in the UK appear to have much longer survival durations compared to varieties protected under UK PVP. Similarly, varieties which switch to CPVO protection from UK protection also have substantially longer median survival durations. Private sector varieties have shorter survival durations than public sector varieties, while varieties produced by foreign entities have longer survival durations than varieties produced by UK firms. Ownership of a variety by one of the top 5 PVP holders does not appear to make a large difference to the survival durations. The significant differences in the Kaplan-Meier survival curves of PVP certificates by strata suggest that the covariates related to PVP regime changes and ownership characteristics may be important determinants of survival durations.

Semi-Parametric and Parametric Models

The results of the extended Cox-model and the lognormal parametric model are presented in Table-3. In interpreting the regression coefficients it should be noted that the dependent variable in the extended Cox model is the hazard of failure while in the parametric model it is survival time. A positive value for a coefficient in the extended Cox model implies that a unit increase in the value of the explanatory variable *increases* the *hazard of failure*. In the parametric model a positive value for a coefficient implies that a unit increase in the value of the explanatory variable will *increase* the *survival time*. We would, therefore, expect the coefficients in the two models to have the opposite signs. The results from the extended Cox-model and the lognormal parametric model are very similar and we will, therefore, discuss only the results of the parametric model below. The last column of the table shows the marginal effects of the covariates for the parametric model on survival durations (in years) calculated at the mean of the explanatory variables.

Table-3 : Results from the Extended Cox-Model and Lognormal Parametric Model

Extended Cox model *(Dependent variable: Hazard of failure)*				**Lognormal parametric model** *(Dependent variable: Survival duration)*			
	Coefficient	**Std. Err.**	**P-value**	**Coefficient**	**Std. Err.**	**P-value**	**Marginal effect on survival duration (years)**
Constant				2.58	0.24	0.00	
Quantity of seed sold (tons)	-0.00003	0.00	0.00	0.00003	0.00	0.00	0.0002
Decade-1980s	0.67	0.11	0.00	-0.68	0.19	0.00	-3.45
Decade-1990s	0.65	0.15	0.00	-0.46	0.22	0.04	-2.60
Decade -2000s	1.20	0.24	0.00	-0.73	0.28	0.01	-3.83
EU legislation-*post 1995 dummy*	0.31	0.13	0.02	-0.11	0.17	0.52	-0.63
Royalties on farm-saved seed-*post 1998 dummy*	-0.39	0.17	0.02	0.34	0.18	0.07	2.06
Produced by UK firm	0.52	0.12	0.00	-0.53	0.12	0.00	-3.59
Protected under the EU law through CPVO	-0.69	0.14	0.00	0.58	0.14	0.00	4.14
Produced by a top-5 company	-0.45	0.11	0.00	0.24	0.12	0.04	1.37
Number of varieties in the market	0.02	0.01	0.00	-0.01	0.01	0.09	-0.08
Produced by a private firm	0.39	0.09	0.00	-0.12	0.12	0.32	-0.71
Switched to CPVO protection	-0.10	0.16	0.51	0.48	0.20	0.01	3.53
Number of varieties =380 Number of observations=1614	Log likelihood - 6456.55	LR $Chi^2(13)$= 310.1	Prob> Chi^2 =0.00	Log-likelihood value=-355 1	LR $Chi^2(13)$ = 126.50	Prob > chi^2 = 0.000	Average survival duration =5.94 years

All the variables are significant at the 10% level of significance except for the dummy variable representing the introduction of EU-wide protection and the dummy variable indexing whether a variety is produced by the private sector or the public sector. Expectedly a larger quantity of seed sold in any year increases the survival duration. This follows from PVP royalties being related to the volume of seed sold. The coefficients of the decadal dummies suggest that there has been a long-term decline in survival durations (in relation to the base decade of 1970s) which may be attributable to institutional factors other than those explicitly included in the model. The introduction of royalties on farm-saved seed has boosted average survival durations by 2.06 years. Varieties protected (originally) under the CPVO or varieties that switch to CPVO protection have longer survival durations (4.14 years and 3.53 years respectively) compared to varieties protected under UK PVP. The effect of the introduction of EU-wide PVP through the CPVO is not significant, but its effect may be picked up by the variable denoting the protection of individual varieties under the CPVO. Development of a variety by a UK entity appears to reduce survival duration by 3.59 years compared with varieties developed by foreign entities. A variety developed by one of the top-5 PVP holders increases survival duration but only by 1.37 years. Private varieties have lower survival durations than public sector varieties but this effect is not significant. Competition reduces survival durations – with every additional existing variety in the market reducing average survival durations by 0.08 years.

The above results suggest that the strengthening of the PVP regime in the UK and the introduction of an EU-wide PVP regime have had a positive impact on survival duration of wheat variety innovations. These positive impacts, however, do not appear to be adequate to offset the long-term decline in survival durations highlighted by the Kaplan-Meier analysis. Shorter survival durations are like to translate into lower returns from protection of innovations and may adversely affect the incentives for investment in conventional plant breeding provided by the PVP regime. This may explain the continuing clamour for stronger protection from the industry – on the lines of stronger patent based protection which is currently available only for genetically modified varieties developed through the application of biotechnology in a limited number of countries. It is true that survival durations are only one of the determinants of returns from variety innovations. Theoretically, the effect of reduced survival durations could be offset by higher per unit PVP royalties on seed sales. However, with volumes in the UK seed market declining over the last decade (by nearly a quarter) and with the increase use of farm-saved seed in wheat (to nearly 50% now from 20% in the early 1990s), this appears to be unlikely. We propose to examine the impact of PVP regime changes and other institutional changes on economic returns from protection in future research.

Conclusions

This paper has attempted a survival analysis of the protected wheat variety innovations in the UK since the mid-1960s focusing on the impacts of changes in the PVP regime. While the post-PVP period has been characterised by an increased flow of new varieties and greater participation by the private sector in plant breeding, there has clearly been a sharp decline in the survival duration of wheat varieties over the last four decades. The average survival duration of new varieties ranges from 4-6 years. The long-term decline in survival durations appears to have been exacerbated by the increased participation of the private sector in plant breeding and increasing competition in markets. This has important implications for the returns that breeders are able to appropriate from their innovations and for the incentives for innovation provided by the PVP regime. The strengthening of plant breeders' rights over new varieties, the introduction of royalties on the use of farm-saved seed of protected varieties and the introduction of an EU-wide system of protection have had a positive effect on survival durations. However, the positive impact of these measures does not appear to have been adequate to offset the decline in survival durations and the consequent decline in the returns appropriated by breeders from variety innovations. The strengthening of the IPR regime for variety innovations may not spur the revival of conventional plant breeding in the UK.

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